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Interferometric Measurement with Squeezed Light

Principal Investigator: Professor Hermann A. Haus
Graduate Students: Keren Bergman and Luc Boivin

The goal of the project is to develop interferometric measurement methods, using squeezed light, with noise levels below the "standard quantum limit." The "standard quantum limit" is the shot noise level. If squeezed radiation is injected into the, normally, unexcited port of a Mach-Zehnder interferometer, the phase shift of the interferometer can be measured in a noise background that is below the shot noise level. In past experiments performed at 1.3 μ wavelength using a nonlinear Sagnac loop[1,2] we have demonstrated shot noise reduction of -5.1 dB[2]. In a phase measurement with a Mach-Zehnder interferometer we have achieved a noise level 3 dB below the shot noise level[3]. In this measurement the losses of the bulk- (rather than fiber-) interferometer prevented the full utilization of the 5.1 dB shot noise reduction.

It is our present goal to achieve improved noise performance by increased noise reduction below the shot noise level. This will be done in a set-up operating in the 800 nm regime with a Ti:Sapphire laser source. In this wavelength regime we can count on higher quantum efficiencies of the photodetectors. The fiber losses are, of course, greater, but in short fiber systems these losses are still acceptably low. The dispersion is positive and squeezing of solitons is out of question. However, theoretical studies have shown[4] that positive dispersion can be beneficial in achieving higher degrees of squeezing compared to the dispersion-free squeezing of Gaussian pulses at 1.3 μ.

In the past year we have built up a Ti:Sapphire based system using short (subpicosecond) pulses at 70 MHz repetition rate. We are still attempting to perfect a source with a 1 GHz repetition rate to overcome the Guided Acoustic Wave Brillouin Scattering (GAWBS) noise problem[5], but have not yet succeeded in reducing its amplitude fluctuations to acceptable levels. In the meantime we intend to perform squeezing experiments with short fibers and short pulses of high peak intensity using the 70 MHz source. This is an alternate way of reducing the GAWBS noise effect[6]. The squeezing system is self-stabilized by provided the same optical paths for the local oscillator pump and squeezed radiation[7].

We have resolved some important theoretical issues.

1. When short pulses are used for squeezing, the finite response time of the Kerr medium must be taken into account. Further, some additional terms appear in the nonlienar Schrödinger equation which, upon quantization, do not preserve the commutators of the electric field operators. The violation of the commutator relations from the finite response time of the Kerr effect was resolved last year by constructing a self-consistant model of the Kerr effect[8]. The appropriate noise sources that prevent the

violation of commutator conservation have been determined. The additional terms, which arise from the rapid variation of the envelope, cause similar violations. We have determined the sources necessary to render the equations self-consistent.

2. The use of positive dispersion for squeezing complicates the problem in that the pulse changes shape while modulating the noise. We have made a full analysis of the squeezing process and found that higher degrees of squeezing can be obtained with positive dispersion than at zero dispersion or with squeezing of solitons with negative dispersion[4]. We found that there is a great deal of coherence across the entire pulse profile. Thus, if detection is with a local oscillator pulse much shorter than the squeezing pulse (windowing), the noise reduction is small or nonexistent. Only when the entire pulse is used as the local oscillator pulse can one achieve appreciable noise reduction[9].

3. Using a computer simulation we have determined the squeezing in a Sagnac interferometer at zero dispersion without any approximations (fully nonlinear analysis)[10].

4. Solitons permit a particularly simple description of squeezing. Following up on previous work on soliton squeezing[11], we have investigated the nature of minimum uncertainty excitations of solitons. We have determined the conditions under which the phase and amplitude of a soliton meets the minimum uncertainty condition, and the alternate case when the minimum uncertainty condition is obeyed, instant by instant, across the envelope of the soliton (under the Slowly Varying Envelope approximation)[12].

5. A complete analysis of the Raman effect on squeezing of cw light (or a square pulse) has been carried out[13].

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